RELATIONS BETWEEN GEOMAGNETIC ACTIVITY AND CIRCULATION INDICES

ROBERT LEE LIVINGSTON

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ROBERT LEE LIVINGSTON

RELATIONS BETWEEN GEOMAGNETIC ACTIVITY AND CIRCULATION INDICES

by

Robert Lee Livingston

Lieutenant Commander, United States Navy

Submitted in partial fulfillment
of the requirements
for the degree of
MASTER OF SCIENCE
IN
AEROLOGY

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PREFACE

This paper is a study of some of the relationships between geomagnetic activity, zonal index, and meridional index. The superposed-epoch method is used to try to find relationships between mean zonal index and various types of geomagnetic activities. The same method is used to try to find relationships between mean meridional index and the various types of geomagnetic activities.

This work was conducted at the United States Naval Postgraduate School, Monterey, California during the winter and spring of 1954 in partial fulfillment of the requirements for the degree of Master of Science in Aerology.

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TABLE OF SYMBOLS & ABBREVIATIONS

D = declination (or "variation") of the magnetic field

F = total intensity of the earth's field

H = horizontal component of the earth's field

Z = vertical component of the earth's field

I = inclination of the earth's field

X = North - South component of the earth's field

Y = East - West component of the earth's field

γ = 10^{-5} oersted

K = geomagnetic index expressing local features such as the systematic diurnal variation in geomagnetic activity

K_s = "standardized" indices freed, insofar as possible from local features

K_p = average of the K_s indices from eleven (at present) magnetic observations

MI = meridional index from 80° W to 0

$|\Delta h_{80°W \rightarrow R^n}^{T}|$ = change in height (in feet) from 80° W to the first trough or ridge at the particular latitude at which MI is computed

$|\Delta h_{R^n \rightarrow 0}^{T}|$ = change in height (in feet) from the last trough or ridge (before reaching 0 longitude) to zero longitude

Δh_{T}^{R} = change in height (in feet) from preceding trough or ridge to first downstream ridge or trough

D_p = day of increase in the twenty-four hour K_p index by nine or more units and a drop of this index within seventy-two hours by nine or more units

Subscript i = $i^{\underline{th}}$ day of observation where $0^{\underline{th}}$ day is the "key" day, $1^{\underline{st}}$ day is "key" day + 1, etc.

Zi = zonal index of an observation in the sample on the $i^{\underline{th}}$ day

ni = total number of observations in the sample on the $i^{\underline{th}}$ day

Zmi = $\frac{\Sigma Zi}{ni}$ = mean value of the zonal index for the $i^{\underline{th}}$ day

$\sigma_{mi}^2 = \frac{\Sigma Zi^2}{ni^2} - \frac{Zmi^2}{ni}$ = Variance of the mean of the sample on the i^{th} day

$$\sigma_m^2 = \frac{n_0\sigma_{m_0}^2 + n_1\sigma_{m_1}^2 + n_2\sigma_{m_2}^2 + n_3\sigma_{m_3}^2 + n_4\sigma_{m_4}^2 + n_5\sigma_{m_5}^2 + n_6\sigma_{m_6}^2}{n_0 + n_1 + n_2 + n_3 + n_4 + n_5 + n_6 - 7}$$

σ_m^2 = unbiased estimate of the variance of the population based on the variances of the samples of all the i^{th} days

$t = \frac{Zmi - Zmo}{\sigma mo}$ = standard normal variate using σmo as an approximation to the standard deviation of the population

$tr = \frac{Zmi - Zmo}{\sigma m}$ = standard normal variate using σm as unbiased estimate of standard deviation of the population

MI_i = meridional index of an observation in the sample on the i^{th} day

$MImi = \frac{\Sigma MIi}{N_i}$ = mean value of the meridional index for the i^{th} day

CHAPTER I

INTRODUCTION

In the past six years many investigations of the effects of geomagnetic activity on various meteorological elements have been carried out. Most of the investigations have been concerned with the study of geomagnetic activity and its effect on pressure. Several of these have lead to interesting conclusions.

Duell and Duell[2] have studied the variation of surface pressure in northwest Europe during the few days following geomagnetically disturbed days and also following geomagnetically quiet days. Their investigation led to the result that surface pressure variations during these periods were linked with events in the upper atmosphere. Craig[1], at the Harvard College Observatory, felt the great need in the field was for an objective statistical analysis with an aim toward providing information as to the probability that the Duell's results did demonstrate some physical relationship. His statistical analysis led him to state "It therefore seems reasonable to reject the hypothesis that geomagnetic activity and surface pressure are unrelated."

Kaciak and Langwell[6] have studied the relation between geomagnetic activity and pressure variations aloft. They did not restrict their investigation to winter months and years of low relative sunspot numbers as did the Duells' and Craig. Their results indicated no relationship between geomagnetically disturbed days and pressure aloft. There did seem to be a relationship between geomagnetically quiet days and pressure aloft - especially at and north of 60° N.

At this point an investigation as to the relations between geomagnetic activity and circulation indices was both natural and desired. No restrictions were made as to sunspot numbers. In some of the investigations no restrictions as to seasons were made. In others, only the winter season was investigated. The "winter" season was chosen as the months January, February, March, April, November, and December.

CHAPTER II

GEOMAGNETIC ACTIVITY

To describe the earth's magnetic field completely at a point, the direction and intensity of the field at that point must be known. Figure I shows schematically the elements which define the magnetic field at a given point. The three magnetic elements D (declination or "variation"), H(horizontal component) and Z(vertical component) are normally recorded at observatories. The total intensity, F, of the earth's field can be determined by computation from the relationship

$$F = H \text{ Sec } I \quad (2.1).$$

The inclination I can be measured by a dip circle or earth inductor. It is also easily calculated from the relation

$$\text{Tan } I = \frac{Z}{H} \quad (2.2)$$

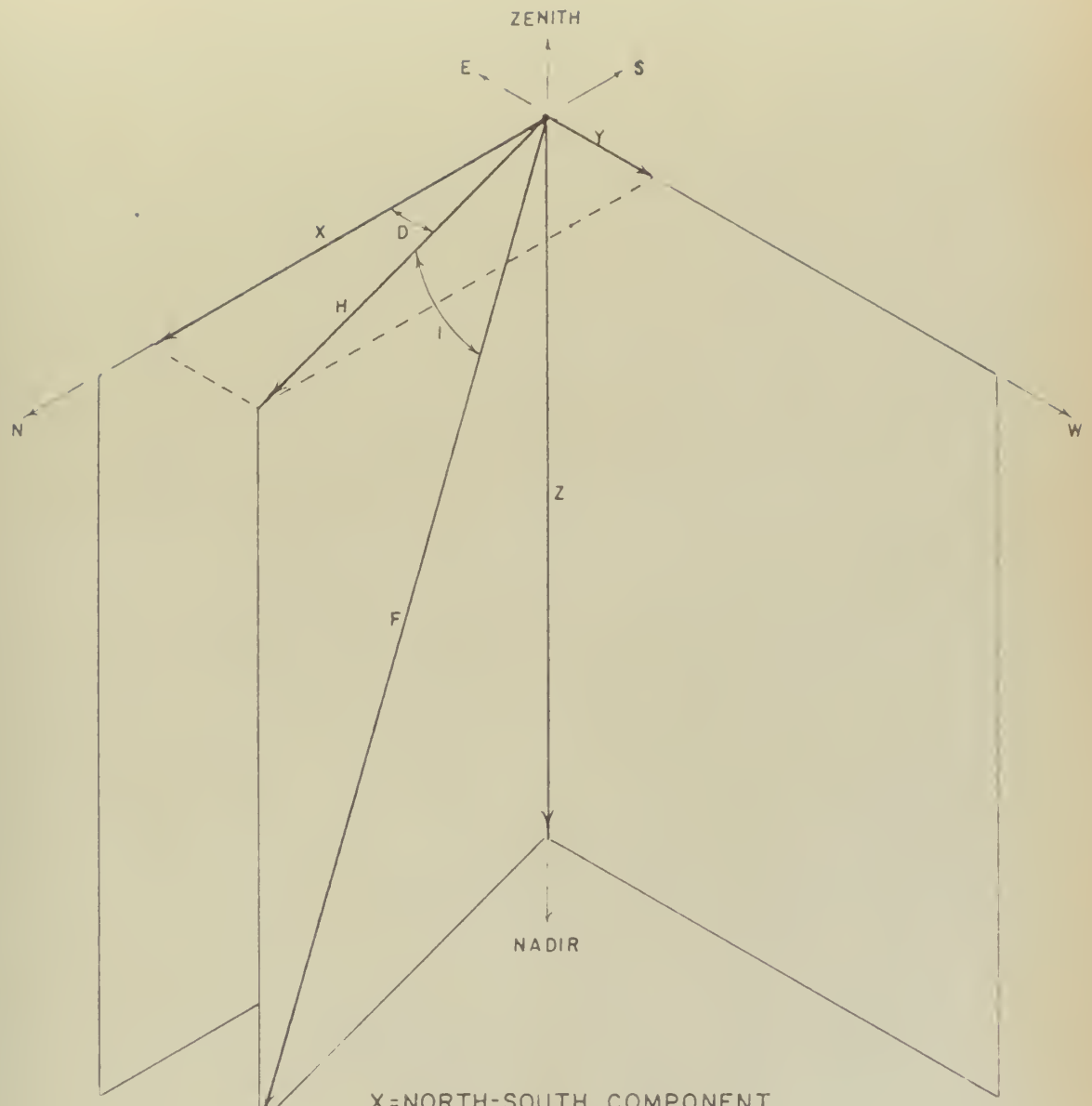
The north component X and the east component Y are computed by the equations

$$X = H \text{ Cos } D \quad (2.3)$$

$$Y = H \text{ Sin } D \quad (2.4)$$

The unit of magnetic intensity is the oersted. In most places on the surface of the earth the intensity of the earth's magnetic field is less than one oersted. It is convenient in the taking of measurements to use the unit gamma (γ) which is 0.00001 oersted.

The total intensity F of the earth's magnetic field is not constant in time. The intensity varies and according to the rates of these variations are classified as secular or transient variations. The secular variations produce perceptible effects over periods of decades or centuries. Their origin is unknown. The transient variations have periods



X=NORTH-SOUTH COMPONENT
Y=EAST-WEST COMPONENT
H=HORIZONTAL INTENSITY
Z=VERTICAL INTENSITY
F=TOTAL INTENSITY
I=INCLINATION
D=DECLINATION

FIG. ELEMENTS OF THE GEOMAGNETIC FIELD

measured in days, hours, or even minutes. There are three types of transient variations namely: (a) solar (b) lunar (c) disturbance variations. We are particularly interested in the disturbance variations and their relation to the circulation indices.

The intensity of these disturbances are measured every three hours by a so called K-index. The range for K= 9 is 500 gamma (one gamma = .00001 oersted). The numerical character figure of the K index is determined from the magnétogram trace every three hours. The K index expresses the degree of irregularities in the systematic diurnal variation of geomagnetism which includes certain local features. There was a need for an abstract of all the individual K-indices in order to express world wide features in the time-changes of geomagnetic disturbance. In 1949 this need was met by the establishment of a new index K_p designed to measure planetary variations in geomagnetic activity. This index was based on "standardized" K_s indices freed, insofar as possible, from local features. At present, eleven observatories have conversion tables assigning a K_s index to their respective K indices. K_p is the average of the eleven K_s indices. The eleven observatories are: Lerwick, Meanook, Sitka, Eskaldemuir, Rude Skov, Agincourt, Wingst, Witteveen, Abinger, Cheltenham, and Amberly.

The indices K and K_p have been defined as measures of the disturbance exhibited by magnetograms. Actually these indices are designed to measure the varying intensity of solar particle radiations P by their geomagnetic effects. These solar particle radiations show their effects mostly in the auroral zones (polar regions). The eleven selected observatories lie within forty-two degrees of the respective

poles of the earth's magnetic axis. According to J. Bartels, of the University of Göttingen, eruptive processes in the so called M regions of the sun generate these particle invasions. These particle invasions are not well correlated with sunspots, bright spots, or solar flares. Ionospheric storms (characterized by a considerable decrease of the electron density in the F layer) are well correlated with geomagnetic disturbances.

CHAPTER III

METHOD OF COLLECTION OF DATA

All zonal profile values were obtained through project Arowa from the National Weather Records Center at Asheville, North Carolina. The records contained the mean geostrophic westerly wind for 5° latitude belts from 10N to 70N for the four octants and the hemisphere. The octant descriptions were given as:

1. 100E to 180
2. 170W to 90W
3. 80W to 0
4. 10E to 90E

Values are in meters per second. Octant three (80°W to 0°) was selected as the zone of investigation due to the frequency of blocks in this area and also due to the fact that some of the investigation involved the use of data from the observatory at Cheltenham, Maryland. This observatory is on the western edge of octant three.

Meridional indices were calculated from the Weather Bureau Daily Series 500 mb synoptic weather maps. The indices were calculated for octant three by starting at 80°W and proceeding to 0°. As the flow changed from south to north or north to south the height change, in feet, from trough to ridge or ridge to trough was recorded. These height changes, regardless of sign, as recorded from 80°W to 0° were added together**

$$MI = \left|\Delta h_{80°W \rightarrow R^{T_n}}\right| + \left|\Delta h_{T}^{R}\right| + \left|\Delta h_{R}^{T}\right| + \cdots\cdots + \left|\Delta h_{R^{T_n} \rightarrow 0°}\right| \quad (3.1)$$

** This sum was the figure actually used in the computations of means and standard deviation.

To change these values to meters per second multiply the sum of the heights by

$$\left(\frac{g}{f}\right)\frac{.3048}{80(\text{Cos }\phi)\ 60 \text{ X } 1853} \qquad (3.2)$$

where g = 9.8 meters per second per second; $f = 2\omega \text{Sin } \phi = 1.454 \text{ X } 10^{-4}$ Sin ϕ.; and ϕ = latitude. Latitudes selected for both zonal and meridional indices were 50°N and 65°N.

All geomagnetic data was taken from the Journal of Geophysical Research. The sum of the Kp index (value of the intensity of disturbances for a twenty-four hour period) for each of the five most quiet days per month was recorded for the entire year 1949. This data was also broken down so that only the winter months were considered. The days so recorded were designated as "quiet key" days. The twenty-four hour Kp index for each of the five most disturbed days per month was recorded for the years 1949 and 1950. These years were also broken down so that only the winter months were considered. The days so recorded were designated as "disturbed key" days.

In selecting "quiet" or "disturbed key" days in this manner it was found that many of the "key" days fell on successive days. Since there was a possibility that this could introduce overlapping influences, other methods of selecting "key" days were used. The first of these methods was the choice of days of s.c. (sudden commencement) or s.c.* (small initial impulse followed by main impulse) as "key" days. These days were selected from Cheltenham, Maryland's records of principal magnetic storms for the years 1949, 1950, and 1951. One s.c. occurred on December 27, 1951 at Cheltenham that was not included in the sample. This was due to the fact that at the time the sample

was being taken, data for this month and year were not available. A second method of selecting well separated "key" days was the selection of the day of increase in the twenty-four hour Kp index by nine or more units and a drop of this index within seventy-two hours by nine or more units. In general this will give a "key" day commencing on the day of increase in particle invasions after they had been relatively low. These days were selected for the winters of 1949, 1950, and 1951 and on the Plates are labeled "Dp". A third and fourth method of selecting "key" days were used. They involved using the twenty-four hour Kp index for the single most disturbed day per month and the twenty-four hour Kp index for the single most quiet day per month. These days were chosen for each month for the years 1949, 1950, and 1951.

CHAPTER IV

APPLICATION OF SUPERPOSED EPOCH METHOD

In order to see the relation, if one exists, between geomagnetic activity and either of the circulation indices all other causes of variation in the circulation indices must be eliminated or held constant. This means that the statistical approach is the most natural and best suited for the investigation. Such a method has been widely used in the past and will be used here. It is known as the Chree "superposed-epoch" Method.

It is necessary first to select certain well defined days of geomagnetic activity called "key" days and second try to determine if the geomagnetic activity of these days does or does not affect the particular parameters we are investigating. Zonal and meridional indices were chosen as the parameters to be investigated. The values of these parameters over a particular octant (80°W to 0°) and at particular latitudes (50°N and 65°N) are recorded for each "key" day as well as several days following the "key" day. By averaging the zonal and meridional indices over all the key days, a mean value for each type of index is obtained for that day. Likewise a mean value of the indices is obtained for each of the days following the key day. In this way we get a typical behavior pattern of the indices for the periods during and after the key day. This pattern should represent the effect of geomagnetic activity on the zonal indices provided all other causes of index variations are eliminated.

There are three major types of index variations: diurnal, annual,

and interdiurnal. The interdiurnal variations are due to variations in the synoptic situation and are assumed to be eliminated due to the size of the sample. The diurnal index changes have been eliminated by using a single value computed for the same period each day. The annual variation, in some cases, has been partially eliminated or minimized by using the same amount of data each month. In other cases only the winter months are considered and therefore an effect characteristic of the winter season is incorporated in the results.

If the subscript i designates the i^{th} day of observation where i = o designates the "key-day", i=1 designates "key-day" plus one; i=2 designates "key-day" plus two; etc. and Zi = zonal index of an observation in the sample on the i^{th} day then the mean value of the zonal index for the i^{th} day is

$$Zmi = \frac{\leqslant Zi}{Ni} \qquad (4.1)$$

where Ni = total number of observations in the sample on the i^{th} day. The variance of the mean of the sample on the i^{th} day is estimated by **

$$\sigma_{mi}^2 = \frac{\leqslant Zi^2}{Ni^2} - \frac{Z_{mi}^2}{Ni} \qquad (4.2)$$

Let us assume that, although the expected value of the population of means for each of the various days (i = 0, 1, 2, 3, 4, 6, 8) may not be the same for each value of i, the variance of the population of means does not depend on i. Under this assumption we can obtain an unbiased estimate of the variance of the population of means based on the variances of the samples of all the i^{th} days.

** Mood (8) page 133

It can be written as**

$$\sigma_m^2 = \frac{N_0\sigma_{m_0}^2 + N_1\sigma_{m_1}^2 + N_2\sigma_{m_2}^2 + N_3\sigma_{m_3}^2 + N_4\sigma_{m_4}^2 + N_6\sigma_{m_6}^2 + N_8\sigma_{m_8}^2}{N_0 + N_1 + N_2 + N_3 + N_4 + N_6 + N_8 - 7} \qquad (4.3)$$

where Ni equals the number of observations in the sample of the $i^{\underline{th}}$ day. The means and variances of the meridional index can be written in the same way using MI for meridional index.

Let us assume that we have an $i^{\underline{th}}$ day sample of individual zonal index (or meridional index) values of sufficient size that the sample means may be considered to be normally distributed. If the null hypothesis that the mean of the zonal index (or meridional index) for the key day is equal to the mean of the index for any of the days following the key day is made, this essentially states that there is no relationship (obtainable with this method and data) between geomagnetic activity and zonal index (or meridional index). If however, testing shows that $Z_{mi} - Z_{mo} \geq 1.96\sigma_m$, then there are only five chances out of a hundred that a deviation of the sample means as large or larger than this could occur due to chance alone. If $Z_{mi} - Z_{mo} \geq 1.96\sigma_m$ it is due to the probability, with 95% confidence, that the samples are not randomly selected and the null hypothesis must be rejected. In view of the manner of selection of key days this implies that the deviation may be attributed to geomagnetic activity.

Using the standard normal variate $t_r = \frac{Z_{mi} - Z_{mo}}{\sigma_m}$ and the table** in Hoel[4], page 243, we find the probabilities of a deviation less than certain values of the standard normal variate is as shown in Table 1.

** Hoel (4) Page 130

Probability (%)	tr	Probability (%)	tr
0	000	60	.842
10	.126	70	1.036
20	.253	80	1.282
30	.385	90	1.645
40	.524	95	1.960
50	.674	99	2.576

TABLE 1

The application of the Chree Method is shown in Tables 2 through 11, which present values of the standard normal variate following the particular choice of key day noted. In all tables an asterisk indicates a value of the standard normal variate in excess of $1.96\sigma_m$.

ith DAY	DISTURBED DAYS 1949 50N							
	ZONAL INDEX				MERIDIONAL INDEX			
	Z_{mi}	σ_{mi}	$t=\frac{Z_{mi}-Z_{mo}}{\sigma_{mo}}$	$t_r=\frac{Z_{mi}-Z_{mo}}{\sigma_m}$	MI_{mi}	σ_{mi}	$t=\frac{MI_{mi}-MI_{mo}}{\sigma_{mo}}$	$t_r=\frac{MI_{mi}-MI_{mo}}{\sigma_m}$
0	16.3	1.04	0	0	22.6	.90	0	0
1	16.9	1.02	.58	.61	22.8	.91	.22	.22
2	17.5	.96	1.15	1.22	21.9	.87	-.78	-.78
3	18.0	.96	1.64	1.73	22.7	.74	.11	.11
4	18.8	.94	2.40*	2.56*	22.7	.85	.11	.11
6	17.1	.87	.77	.82	22.8	1.02	.22	.22
8	16.6	1.00	.29	.36	22.8	.91	.22	.22
	$\sigma_{mo}=1.04$		$\sigma_m=.98$		$\sigma_{mo}=.90$		$\sigma_m=.90$	

TABLE 2

ith DAY	DISTURBED DAYS WINTER 1949 50N			
	ZONAL INDEX			
	Z_{mi}	σ_{mi}	$t=\frac{Z_{mi}-Z_{mo}}{\sigma_{mo}}$	$t_r=\frac{Z_{mi}-Z_{mo}}{\sigma_m}$
0	18.8	1.48	0	0
1	19.6	1.45	.54	.55
2	20.6	1.33	1.22	1.24
3	21.2	1.29	1.62	1.65
4	21.4	1.28	1.76	1.79
6	18.7	1.30	-.07	-.07
8	17.9	1.78	-.61	-.62
	$\sigma_{mo}=1.48$		$\sigma_m=1.45$	

TABLE 3

ith DAY	DISTURBED DAYS 1950 50N							
	ZONAL INDEX				MERIDIONAL INDEX			
	Z_{mi}	σ_{mi}	$t=\frac{Z_{mi}-Z_{mo}}{\sigma_{mo}}$	$t_r=\frac{Z_{mi}-Z_{mo}}{\sigma_m}$	MI_{mi}	σ_{mi}	$t=\frac{MI_{mi}-MI_{mo}}{\sigma_{mo}}$	$t_r=\frac{MI_{mi}-MI_{mo}}{\sigma_m}$
0	15.0	1.11	0	0	21.7	1.10	0	0
1	15.0	.88	0	0	21.4	1.09	-.27	-.30
2	15.6	1.06	.54	.55	21.3	1.04	-.36	-.40
3	17.1	1.24	1.89	1.93	21.0	.91	-.64	-.70
4	17.8	1.18	2.52*	2.56*	21.5	.95	-.18	-.20
6	17.5	1.11	2.25*	2.29*	20.4	.93	-1.18	-.130
8	16.3	.96	1.17	1.19	22.2	.86	.45	.50
	σ_{mo}= 1.11 σ_m = 1.09				σ_{mo} = 1.10 σ_m = 1.00			

TABLE 4

ith DAY	DISTURBED DAYS WINTER 1950 50N			
	ZONAL INDEX			
	Z_{mi}	σ_{mi}	$t=\frac{Z_{mi}-Z_{mo}}{\sigma_{mo}}$	$t_r=\frac{Z_{mi}-Z_{mo}}{\sigma_m}$
0	14.4	2.02	0	0
1	14.1	1.44	-.15	-.17
2	15.4	1.74	.50	.58
3	15.7	1.70	.64	.76
4	16.5	1.43	1.04	1.22
6	18.9	1.77	2.22*	2.62*
8	16.7	1.67	1.14	1.34
	σ_{mo}=2.02		σ_m = 1.72	

TABLE 5

ith DAY	QUIETEST DAY/MONTH 1949, 1950, 1951 50N							
	ZONAL INDEX				MERIDIONAL INDEX			
	Z_{mi}	σ_{mi}	$t=\frac{Z_{mi}-Z_{mo}}{\sigma_{mo}}$	$t_r=\frac{Z_{mi}-Z_{mo}}{\sigma_m}$	MI_{mi}	σ_{mi}	$t=\frac{MI_{mi}-MI_{mo}}{\sigma_{mo}}$	$t_r=\frac{MI_{mi}-MI_{mo}}{\sigma_m}$
0	13.4	1.20	0	0	22.1	1.10	0	0
1	14.0	1.49	.50	.41	21.3	1.44	-.73	-.56
2	13.6	1.44	.17	.14	22.2	1.65	.91	.07
3	15.0	1.54	1.33	1.10	20.7	1.18	-1.27	-.98
4	14.4	1.72	.83	.69	22.7	1.30	.55	.42
6	14.9	1.33	1.25	1.03	22.6	1.33	.45	.35
8	15.4	1.14	1.67	1.38	22.3	1.65	.18	.14
	$\sigma_{mo}=$ 1.20		$\sigma_m=$ 1.45		$\sigma_{mo}=$ 1.10		$\sigma_m=$ 1.42	

TABLE 6

ith DAY	QUIET DAYS 1949 50N			
	ZONAL INDEX			
	Z_{mi}	σ_{mi}	$t=\frac{Z_{mi}-Z_{mo}}{\sigma_{mo}}$	$t_r=\frac{Z_{mi}-Z_{mo}}{\sigma_m}$
0	16.2	.95	0	0
1	15.6	1.05	-.63	-.59
2	15.8	.99	-.42	-.39
3	15.6	1.02	-.63	-.59
4	15.9	1.07	-.32	-.29
6	17.4	1.10	1.26	1.18
8	18.5	.88	2.46*	2.29*
	$\sigma_{mo}=$ .95		$\sigma_m=$ 1.02	

TABLE 7

ith DAY	MOST DISTURBED DAY/MONTH 1949 1950 1951 50N ZONAL INDEX				MERIDIONAL INDEX			
	Z_{mi}	σ_{mi}	$t=\frac{Z_{mi}-Z_{mo}}{\sigma_{mo}}$	$t_r=\frac{Z_{mi}-Z_{mo}}{\sigma_m}$	MI_{mi}	σ_{mi}	$t=\frac{MI_{mi}-MI_{mo}}{\sigma_{mo}}$	$t_r=\frac{MI_{mi}-MI_{mo}}{\sigma_m}$
0	15.3	1.40	0	0	20.8	1.50	0	0
1	15.2	1.43	-.07	-.07	23.9	1.62	2.06*	2.40*
2	17.3	1.28	1.43	1.35	20.4	1.23	-.27	-.31
3	18.0	1.62	1.93	1.82	21.0	1.04	.13	.15
4	18.6	1.79	2.36*	2.23*	20.9	.96	.07	.08
6	15.4	1.09	.07	.07	22.3	1.17	1.00	1.16
8	14.9	1.45	-.29	-.27	23.5	1.22	1.80	2.09*
	σ_{mo}= 1.40		σ_m= 1.48		σ_{mo} = 1.50		σ_m = 1.29	

TABLE 8

ith DAY	QUIET DAYS WINTER 1949 50N ZONAL INDEX			
	Z_{mi}	σ_{mi}	$t=\frac{Z_{mi}-Z_{mo}}{\sigma_{mo}}$	$t_r=\frac{Z_{mi}-Z_{mo}}{\sigma_m}$
0	17.9	1.41	0	0
1	18.2	1.50	.21	.19
2	18.2	1.60	.21	.19
3	17.4	1.50	-.35	-.32
4	18.0	1.60	.071	.066
6	20.3	1.70	1.70	1.56
8	21.4	1.20	2.48*	2.27*
	σ_{mo}= 1.41		σ_m= 1.54	

TABLE 9

i th DAY	SUDDEN COMMENCEMENTS DURING WINTERS 1949 1950 1951															
	ZONAL INDEX								MERIDIONAL INDEX							
	50°N				65°N				50°N				65°N			
	Z_{mi}	σ_{mi}	t	t_r	Z_{mi}	σ_{mi}	t	t_r	MI_{mi}	σ_{mi}	t	t_r	MI_{mi}	σ_{mi}	t	t_r
0	12.1	2.20	0	0	10.1	1.60	0	0	25.3	1.10	0	0	14.1	1.10	0	0
1	15.2	1.94	1.41	1.72	5.4	1.57	-2.94*	-2.83*	25.4	.82	.09	.06	14.7	1.15	.55	.49
2	14.4	1.69	1.04	1.28	7.0	1.55	-1.94	-1.87	26.5	1.66	1.09	.74	13.9	1.07	-.18	-.16
3	14.6	1.31	1.14	1.39	5.3	2.05	-3.00*	-2.89*	24.5	1.57	-.73	-.50	13.7	1.16	-.36	-.32
4	16.1	1.39	1.82	2.22*	4.8	1.69	-3.31*	-3.19*	22.3	1.35	-2.72*	-1.86	12.4	.99	-1.54	-1.38
6	16.0	1.64	1.77	2.16*	5.3	1.33	-3.00*	-2.89*	24.4	1.50	-.82	-.56	14.1	1.11	0	0
8	12.7	1.82	.27	.33	6.6	1.31	-2.19*	-2.10*	27.0	2.42	1.55	1.05	14.5	1.62	.36	.32
	σ_{mo}= 2.20 σ_m =1.80				σ_{mo}=1.60 σ_m= 1.66				σ_{mo}= 1.10 σ_m=1.61				σ_{mo}= 1.10 σ_m= 1.23			

TABLE 10

i th DAY	D_p DURING WINTERS 1949 1950 1951															
	ZONAL INDEX								MERIDIONAL INDEX							
	50°N				65°N				50°N				65°N			
	Z_{mi}	σ_{mi}	t	t_r	Z_{mi}	σ_{mi}	t	t_r	MI_{mi}	σ_{mi}	t	t_r	MI_{mi}	σ_{mi}	t	t_r
0	16.6	1.10	0	0	5.9	1.00	0	0	24.7	1.10	0	0	14.8	.70	0	0
1	17.1	1.10	.46	.44	5.8	.79	-.10	-.11	24.9	1.19	.18	.19	15.7	.85	1.29	1.14
2	17.7	1.08	1.00	.97	4.6	.91	-1.30	-1.46	22.4	1.11	-2.09*	-2.15*	14.0	.76	-1.14	-1.01
3	18.1	1.14	1.36	1.33	4.2	.89	-1.70	-1.91	21.9	.99	-2.54*	-2.62*	14.5	.71	-.43	-.38
4	18.6	1.13	1.82	1.77	4.1	.81	-1.80	-2.02*	23.1	1.02	-1.46	-1.50	14.3	.77	-.71	-.63
6	18.3	1.00	1.54	1.50	4.7	.93	-1.20	-1.35	24.5	.99	-.18	-.19	14.5	.88	-.43	-.38
8	18.3	1.25	1.54	1.50	4.0	.86	-1.90	-2.14	23.7	1.02	-.91	-.93	15.0	.78	.29	.25
	σ_{mo}= 1.10 σ_m =1.13				σ_{mo}=1.00 σ_m=.89				σ_{mo}= 1.10 σ_m= 1.07				σ_{mo}= .70 σ_m= .79			

TABLE 11

CHAPTER V

DISCUSSION OF RESULTS AND CONCLUSIONS

The results of the Tables 2 through 11 are depicted in graphical form in Plates I through IV. The standard deviation σ_{mo} was used first as a measure of the standard deviation of the mean of the population. Black dashed lines were drawn at distances $\pm\sigma_{mo}$, $\pm 2\sigma_{mo}$ so that it would be a matter of easy inspection to determine the days which give deviations in the neighborhood of $\pm 2\sigma_{mo}$. A better estimate of the standard deviation of the population of means, σ_m of equation 4.3, was then devised, and the appropriate $\pm\sigma_m$, $\pm 2\sigma_m$ boundaries delineated on the plates in red dashed lines. Tests of significance relative to the $2\sigma_m$ limits are probably to be preferred although in some cases, there is little difference between σ_m and σ_{mo}.

Plates I and II show the variations of zonal indices following various selections of "key" days and Plates III and IV show the variations of meridional indices following the same selections of "key" days as on Plates I and II. On Plate I, sections (3), (5), and (7) (essentially cases of disturbed geomagnetic activity) show variations at 50°N on the fourth day in excess of $2\sigma_m$. On Plate II, section (2) (most disturbed days) also shows a fourth day variation at 50°N in excess of $2\sigma_m$. In addition, Plate II, section (3) (dealing with another well marked type of disturbance) shows a similar trend at 50°N but the amount of variation on the fourth day is not quite at the $2\sigma_m$ level. These results indicate that the value of the mean zonal index at 50°N should be considerably greater on the fourth day following geomagnetic disturbances

than on the "key" day. Note the general increase in the value of the mean zonal index occurring between "disturbed key" day and "key" day plus four. This increasing trend, occurring as it does in all tests at 50°N involving disturbed days appears to indicate a significant development in the general circulation.

Plate I, sections (1) and (2), showing variations of zonal indices at 50°N following "quiet key" days in 1949 has no variation greater than $2\sigma_m$ except on the eighth day. This implies that the value of the mean zonal index will be greater on the eighth day following quiet days than on the "key" day. This trend toward an increase on the eighth day can be seen independently from Plate II section (1), although not at the $2\sigma_m$ level. The increase between roughly the third and eighth days following "quiet key" day is similar in slope to that occurring just after "disturbed key" day. This seems to indicate that the zonal index variation eight days after "quiet key" day could be due to the occurrence of a geomagnetically disturbed day at about quiet day plus three since on the long term average these should be 3 days apart in a 30 day month.

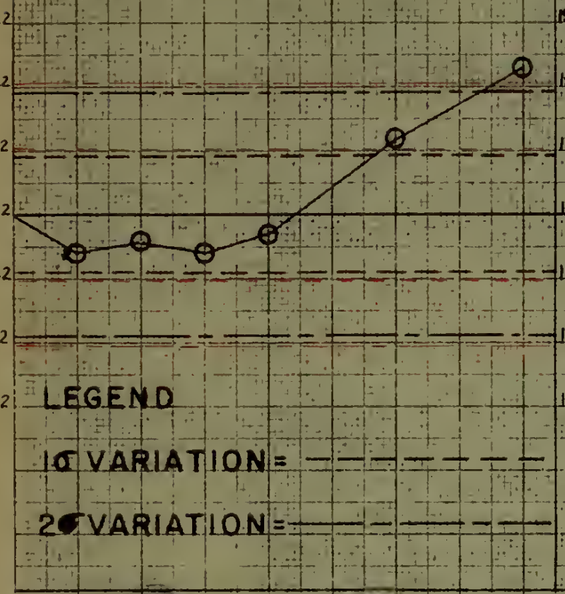
For tests at 65°N Plate I section (8) and Plate II section (4) imply that the value of the mean zonal index drops to a minimum on the fourth day following geomagnetic disturbances. It is interesting to note that the minimum at 65°N and the maximum at 50°N occur on the same day following geomagnetic disturbances, namely the fourth day. Meteorologically this seems to imply that the circulation is altered in the direction of a single strong-peaked zonal profile, corresponding to the classical "high index" stage (cf. for example Chapter II of "Forecasting in Middle Latitudes" by Riehl[9]).

The meridional indices on Plates III and IV do not seem to have as regular or well pronounced variations as the zonal indices. Tests giving variations in excess of $2\sigma_m$ or a variation very close to this value are shown in Plate III section (4) and Plate IV sections (1) and (3). Sections (1) and (3), Plate IV, do suggest a maximum decrease in the mean meridional index on the third or fourth day following the "key" day. This appears to be an independent substantiation of the results concerning zonal index since synoptic experience indicates that the classical "high index" is accompanied by weak meridional index.

This study indicates that a relationship exists between disturbed geomagnetic activity and the general circulation. The relationship indicated is that following a geomagnetically disturbed day one might, on the average, expect a trend toward the classical "high index" pattern at the 500 millibar level from 0° longitude to 80°W (i.e. octant three) and along 50°N latitude.

For further work along this line, fruitful results might also be derived from the consideration of (1) a different selection of "key" days (2) an investigation of the behavior of circulation indices on days before "key" days (3) a study of geomagnetic activity as related to CIT Weather Types or changes in Weather Types.

① QUIET DAYS 1949 50N

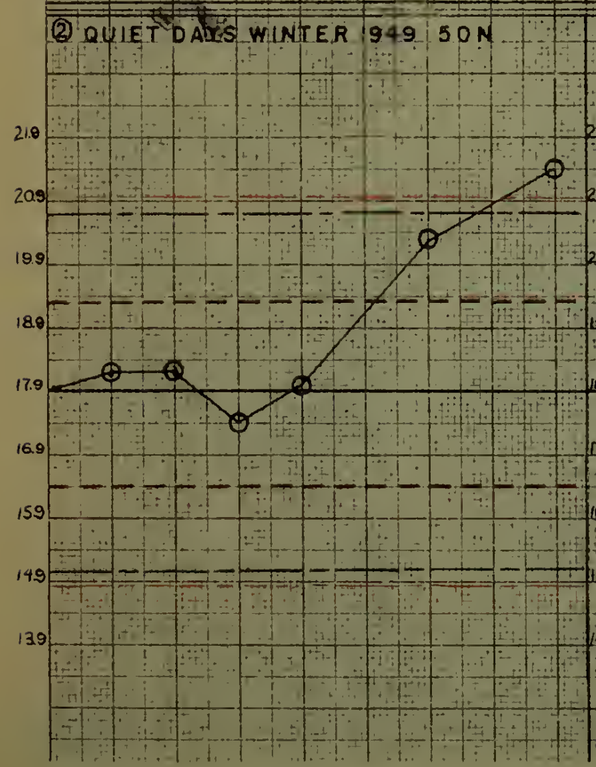


LEGEND

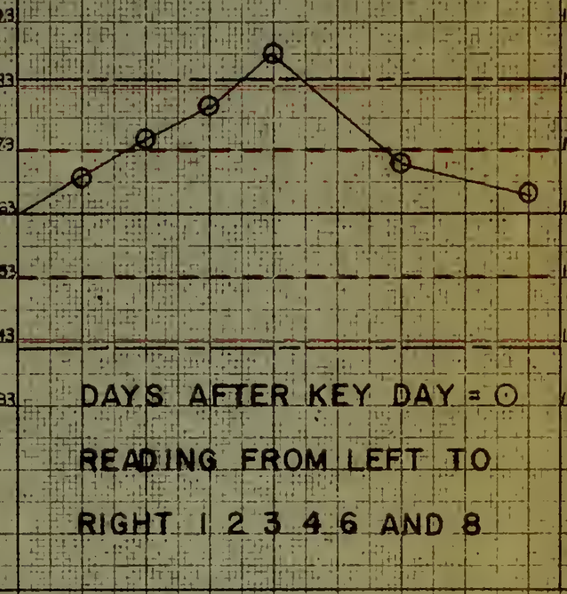
1σ VARIATION = ———————

2σ VARIATION = — — — — —

② QUIET DAYS WINTER 1949 50N



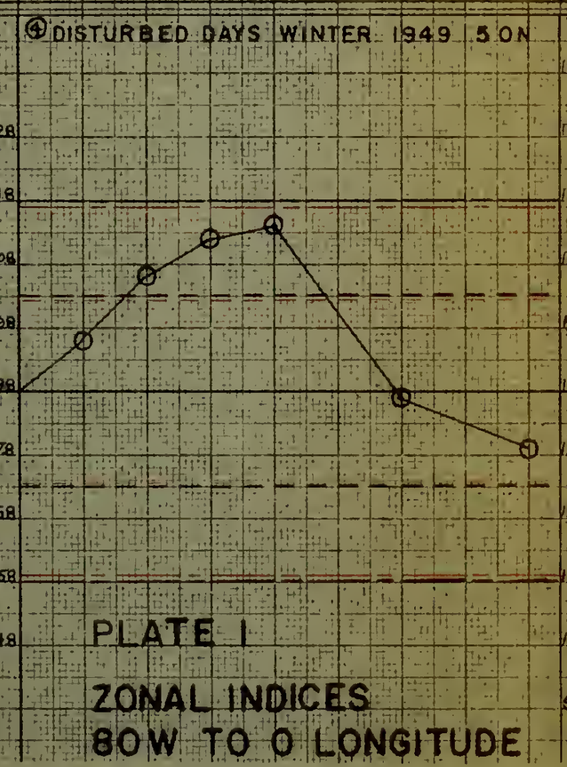
③ DISTURBED DAYS 1949 50N



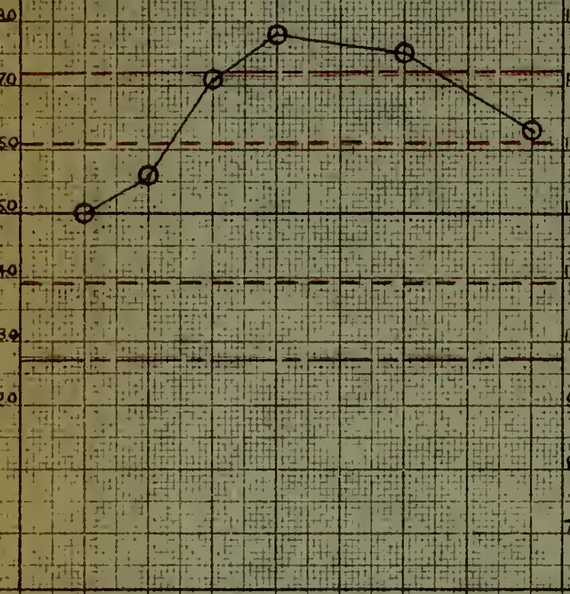
DAYS AFTER KEY DAY = ⊙

READING FROM LEFT TO RIGHT 1 2 3 4 6 AND 8

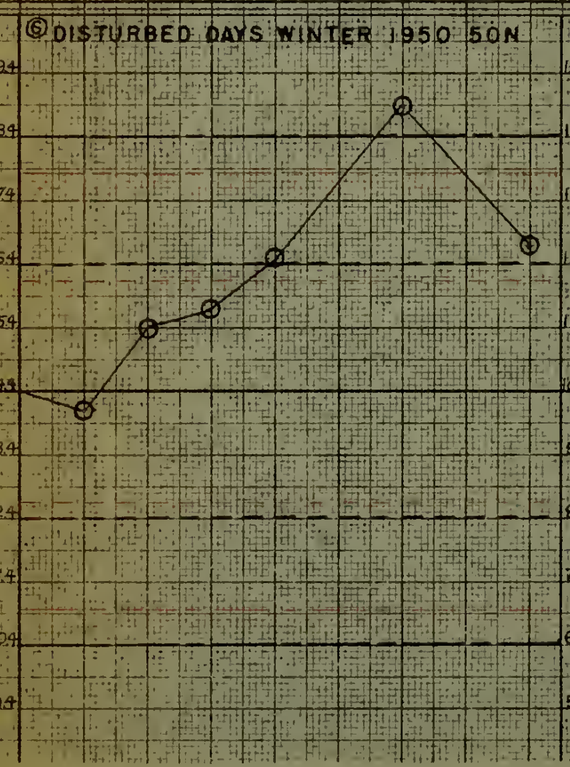
④ DISTURBED DAYS WINTER 1949 50N



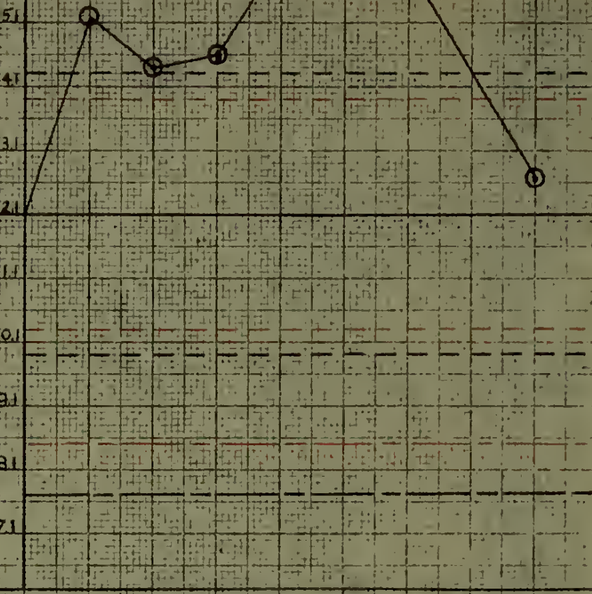
⑤ DISTURBED DAYS 1950 50N



⑥ DISTURBED DAYS WINTER 1950 50N



⑦ S.C. WINTERS 1949 1950 1951 50N



⑧ S.C. WINTERS 1949 1950 1951 65N

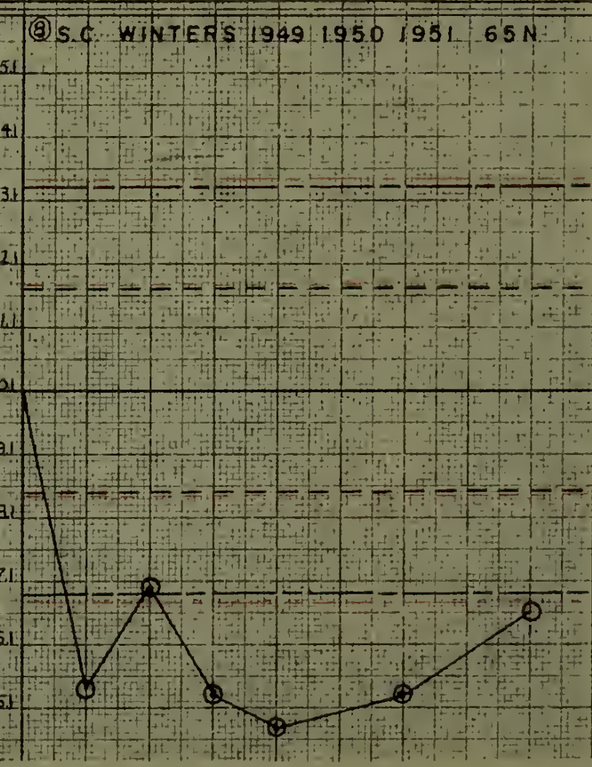
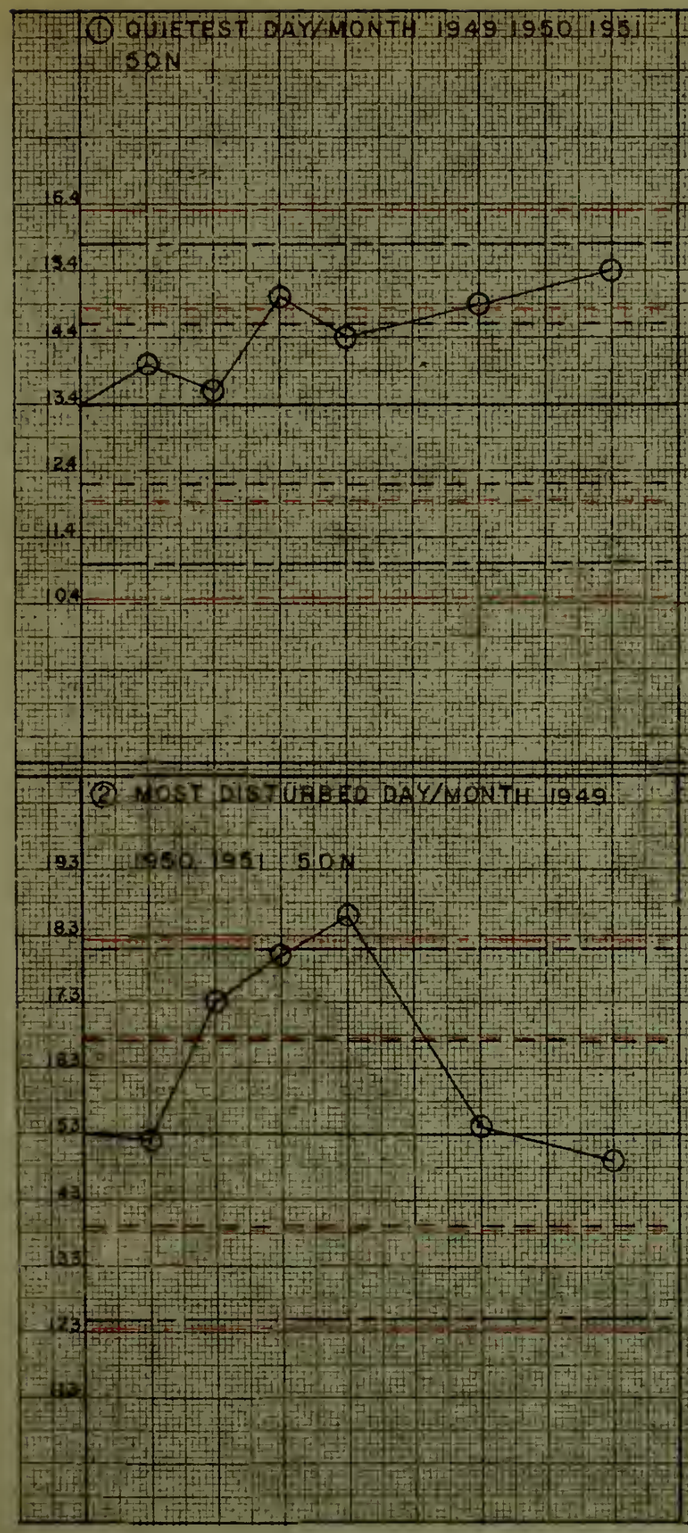


PLATE I

ZONAL INDICES
80W TO 0 LONGITUDE



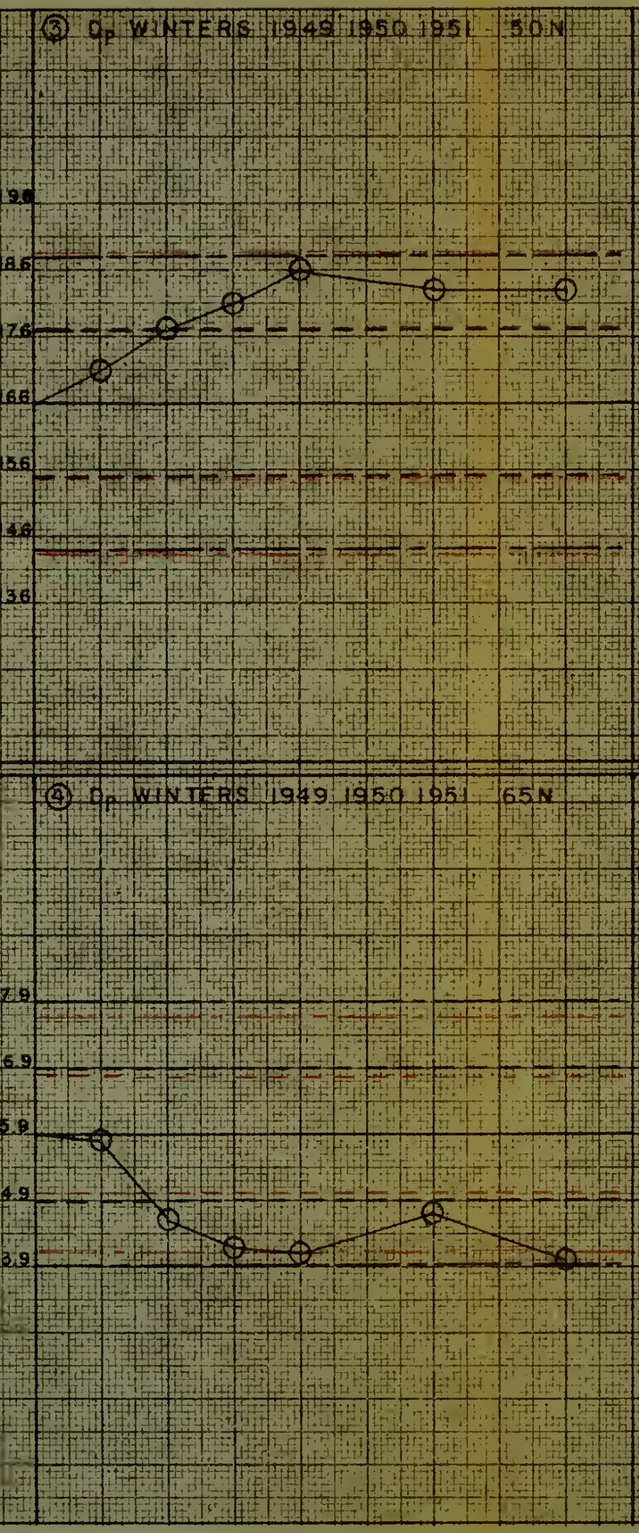


PLATE II

ZONAL INDICES

80W TO 0 LONGITUDE

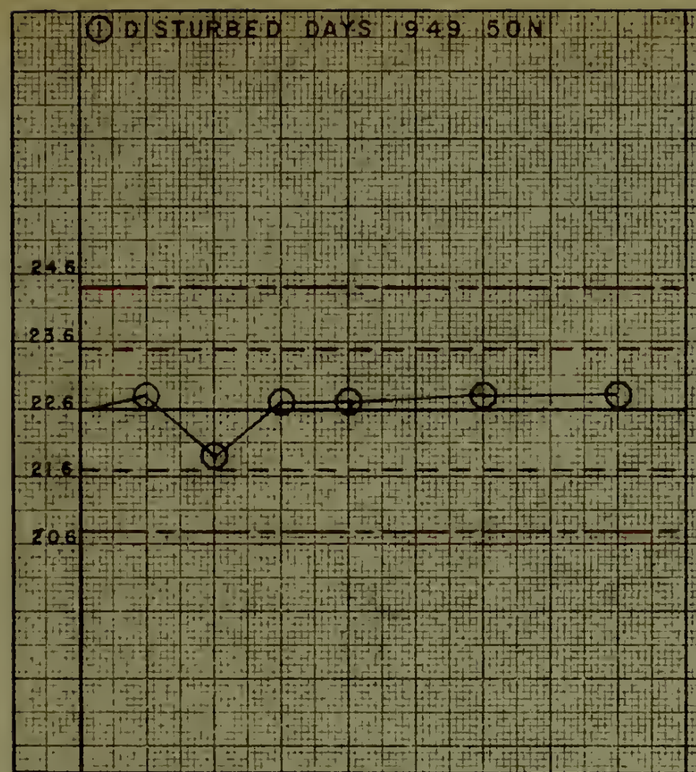
LEGEND

1σ VARIATION = - - - - - - - - -

2σ VARIATION = ——— - ——— ———

DAYS AFTER KEY DAY = ○

READING FROM LEFT TO RIGHT 1 2 3 4 6 AND 8



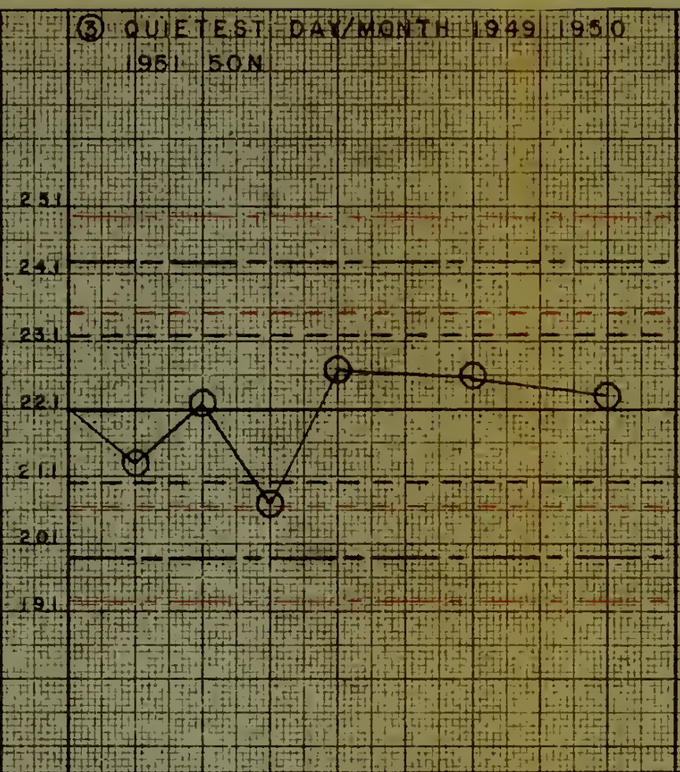
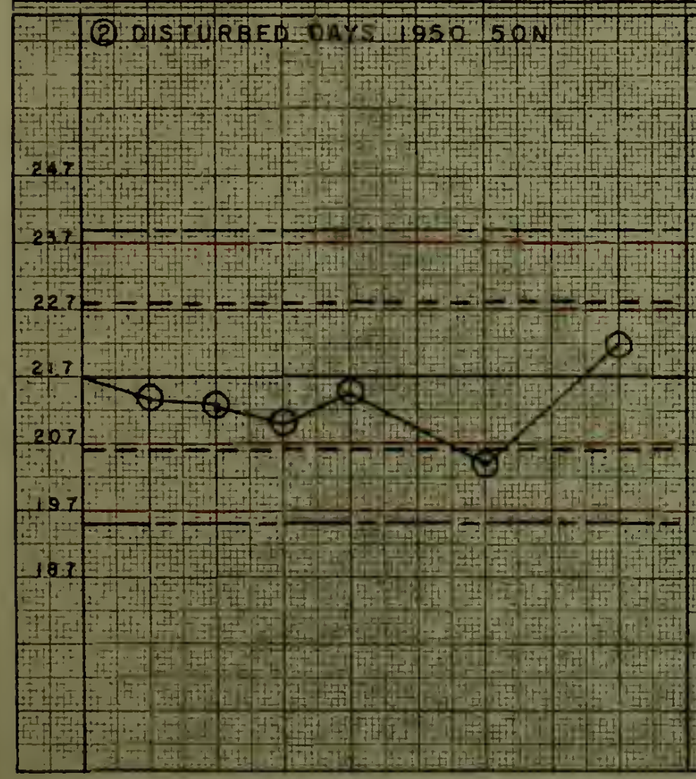
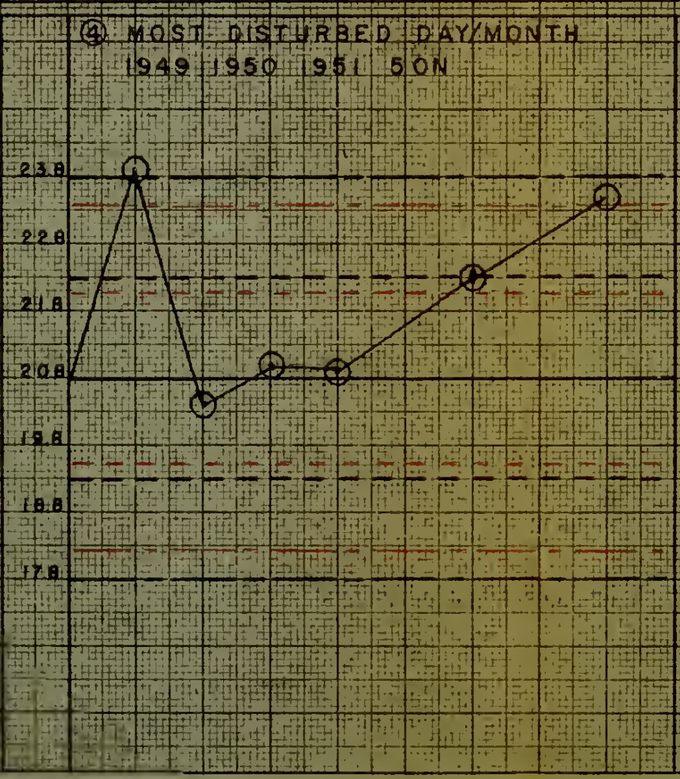


PLATE III

MERIDIONAL INDICES

BOW TO 0 LONGITUDE





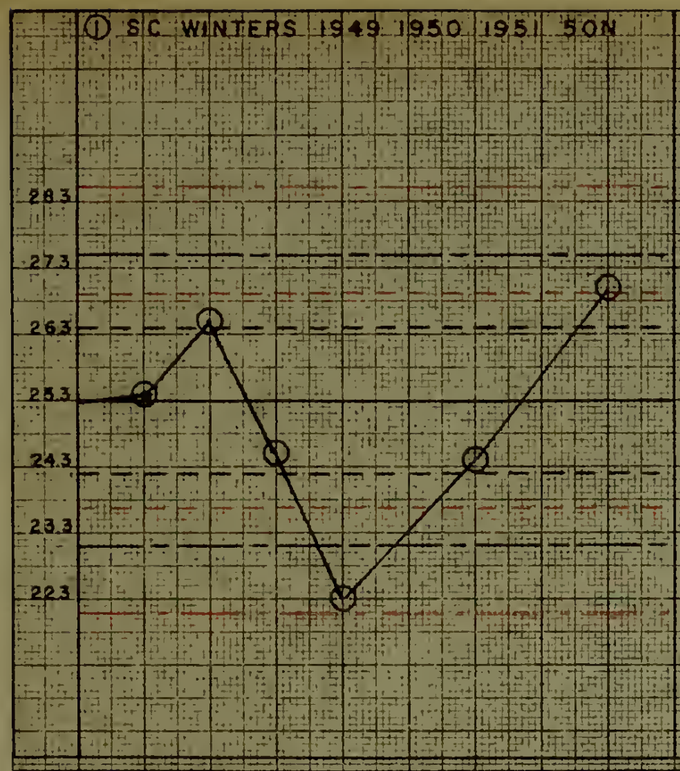
LEGEND

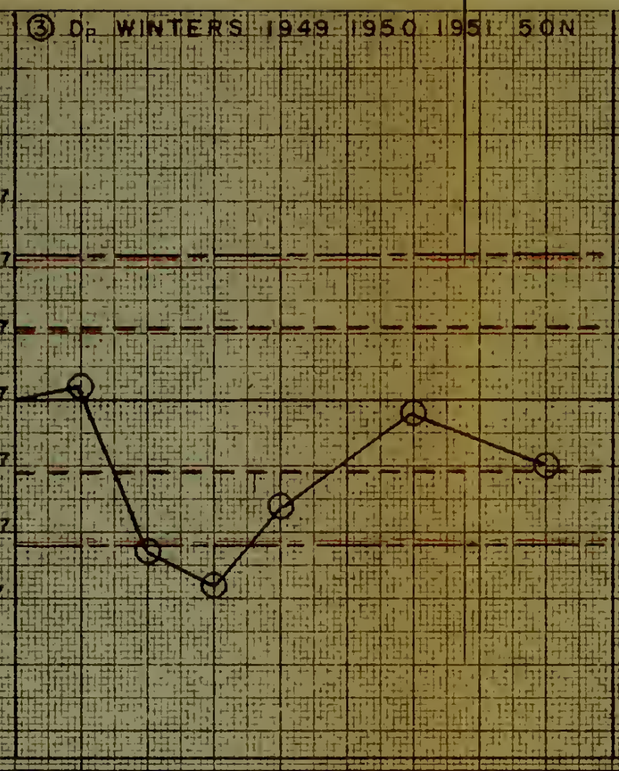
1σ VARIATION = - - - - - - - - -

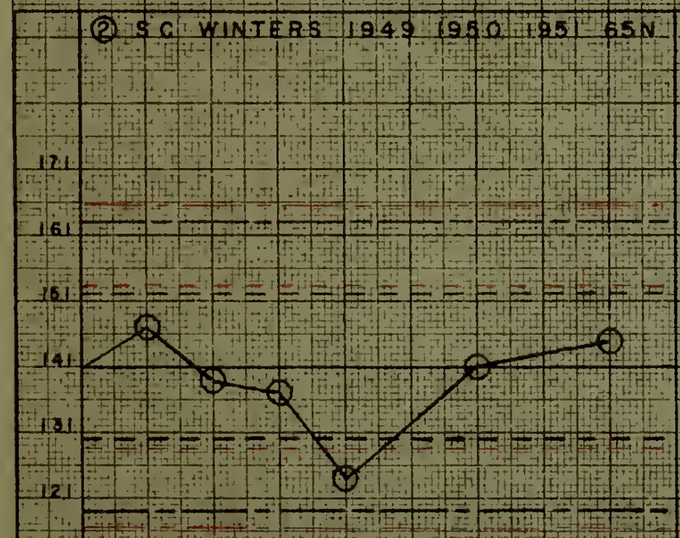
2σ VARIATION = — — — — — — —

DAYS AFTER KEY DAY = ⊙

READING FROM LEFT TO RIGHT 1 2 3 4 6 AND 8







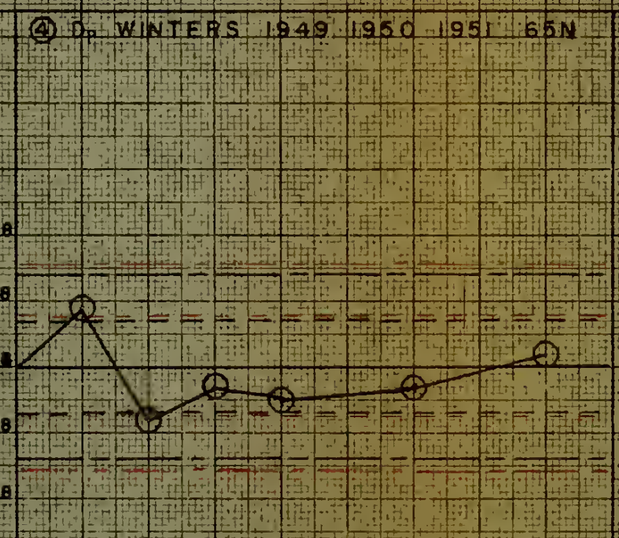


PLATE IV

MERIDIONAL INDICES

BOW TO 0 LONGITUDE

LEGEND

1σ VARIATION = – – – – – – – –

2σ VARIATION = ——— ——— ———

DAYS AFTER KEY DAY = ①

READING FROM LEFT TO

RIGHT 1 2 3 4 6 AND 8

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